Data-Driven Dark Energy: Probing $w(a)$ with Flexknots

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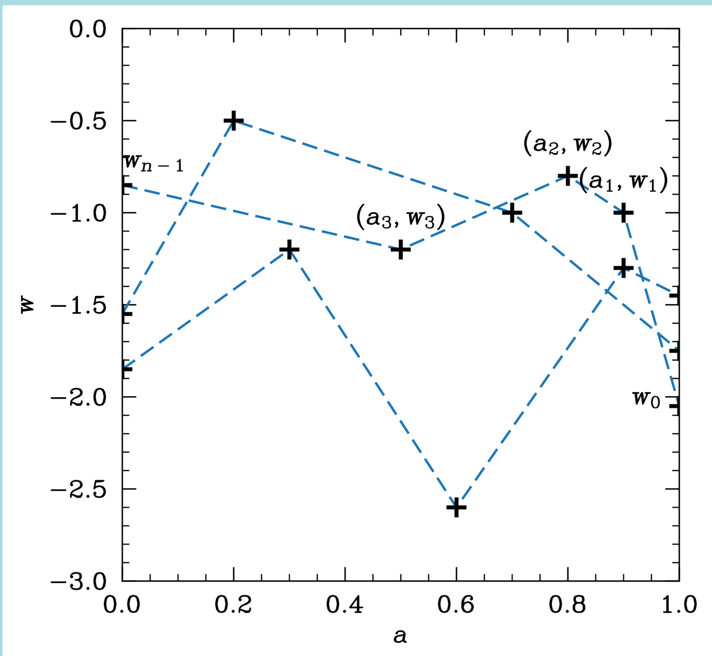
Cosmic acceleration is still a mystery: the standard ΛCDM model ($w = -1$) fits current data but offers no insight into the underlying physics. To let the data speak for themselves, we reconstructed the dark energy equation of state $w(a)$ nonparametrically via a "flexknot" spline. Applying this to DESI BAO plus Pantheon+ or DES5Y Type Ia supernovae (SNe) uncovers a W-shaped $w(a)$ – two distinct features at high and low redshift that simple wCDM or CPL cannot capture. Our results hint that dark energy may evolve in ways beyond standard parameterisations.

arXiv:2503.08658, arXiv:2503.17342 [1, 2]

Flexknots

- Flexknots [3, 4] are a flexible parameterisation of 1D functions.
- The nested sampler [5, 6] `PolyChord` [7, 8] was used to compute the evidence and produce posterior samples for flexknots with **1–20** knots.
- To produce an overall functional posterior, samples from all 20 flexknots are combined, weighted in proportion to their evidence.



Examples of flexknot $w(a)$ with either two or three knots.

BAO and Ia SNe in JAX

Off-the-shelf likelihoods for BAO and Type Ia SNe are widespread, such as `Cobaya` [9], but it was useful to write our own.

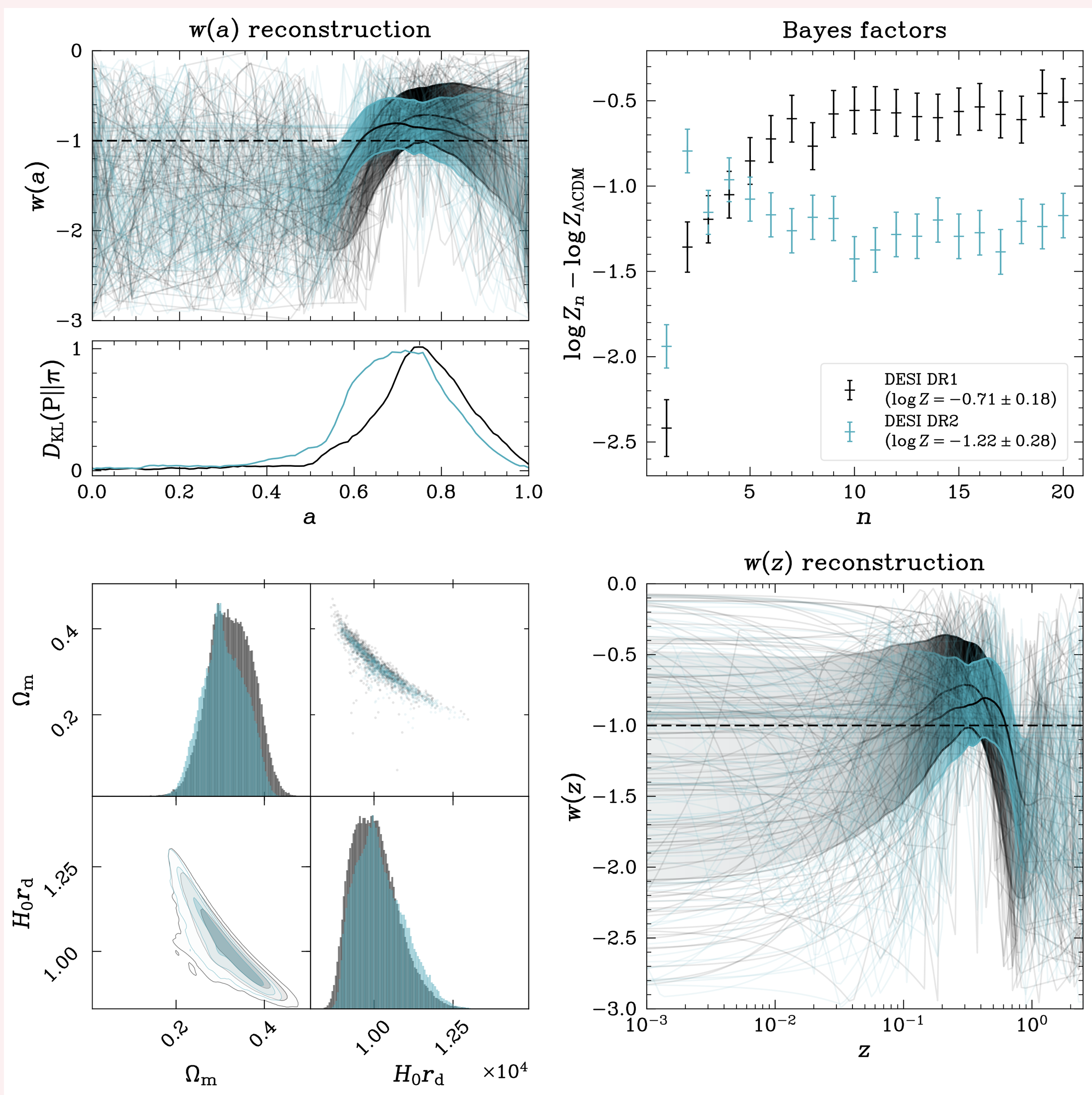
- **Hidden decisions** While convenient, these likelihoods may contain decisions which are not obvious to the user without reading the source code, such as the low-z cut in `Cobaya`'s Pantheon+.
- **Simplicity** With no CMB, the cosmological distance calculations required are straightforward and require little other than `numpy`, `scipy`, and a 1D integration strategy.
- **Analytic marginalisation** The likelihoods themselves are Gaussian, we were able to analytically marginalise out the Hubble constant, H_0, and the absolute magnitude of the Type Ia SNe, M_B [1].
- **JAX vectorisation** We have implemented a `JAX`-based version of these distance calculations to work with David Yallup's `blackjax` nested sampler [10]. ΛCDM takes only a few seconds on a laptop!

$$\frac{D_M(z)}{r_d} = \frac{c}{r_d}\int_0^z \frac{dz'}{H(z')} = \frac{c}{r_d H_0}\int_0^z \frac{dz'}{h(z')}, \quad (\Omega_k = 0).$$

DESI DR1 vs DR2

The Dark Energy Spectroscopic Instrument (DESI) [15] measures Baryon Acoustic Oscillations (BAO), echoes of pre-recombination sound waves imprinted in the large-scale structure of the universe.

DESI BAO

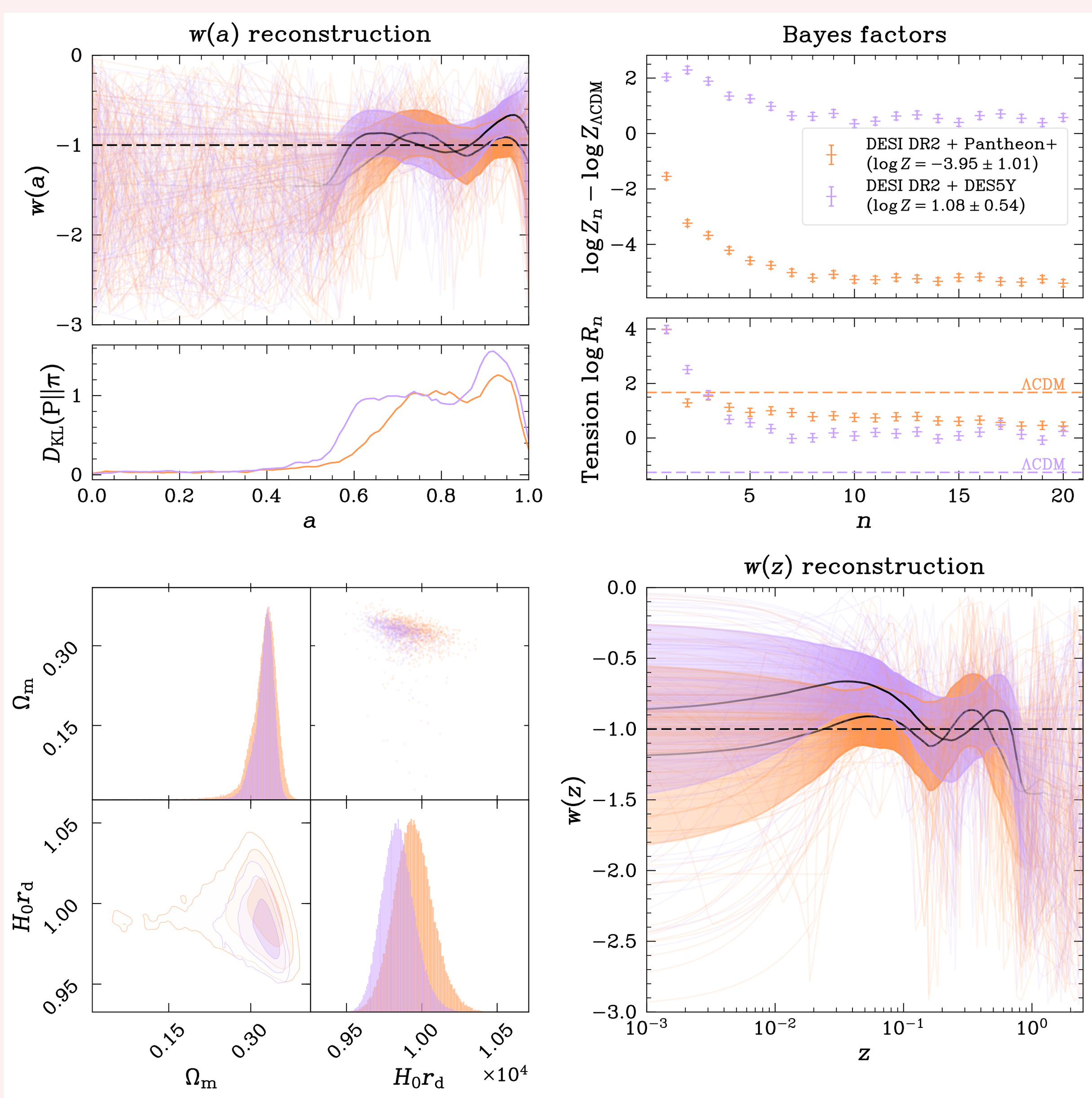


DESI DR2 + Type Ia SNe

Combining Type Ia SNe [17, 18] with BAO measurements provides further constraints on the evolution of $w(a)$. However, it is possible the data are in tension. This is quantified by the tension ratio [16]:

$$\log R = \log Z(\text{BAO} + \text{SNe}) - \log Z(\text{BAO}) - \log Z(\text{SNe}).$$

DESI + Pantheon+ vs DESI + DES5Y



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